The use of RELAP5 in the structural verification of a Swedish NPP

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The Simpevarp Peninsular

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OKG AB in figures

- **Unit 1 (O1) 1972 first NPP in Sweden, 490 MWe**
- **Unit 2 (O2) 1974 620 MWe (EPU 2011 106% to 135%)**
- **Unit 3 (O3) 1985 1200 MWe (EPU 2009 109% to 129%)**
- **CLAB, an intermediate storage facility for spent fuel (Recent capacity increase to 200%)**

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RELAP5 can be used in different applications

- LOCA and transient analysis
- Pipe break flows
- Flooding
- Pressure build-up in rooms
- Forces and pressure on piping
- Pressure and forces on RPV internals

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How has RELAP5 been used in the structural verification?

- Relap5 has been used in Sweden since the middle of the nineties for calculating thermo-hydraulic forces in piping and for forces on the RPV and RPV internals
- Forces and pressures are then used in a structure model to determine strains, stresses and displacements
- These are then evaluated to prove the structural integrity

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Type of load generating events analysed

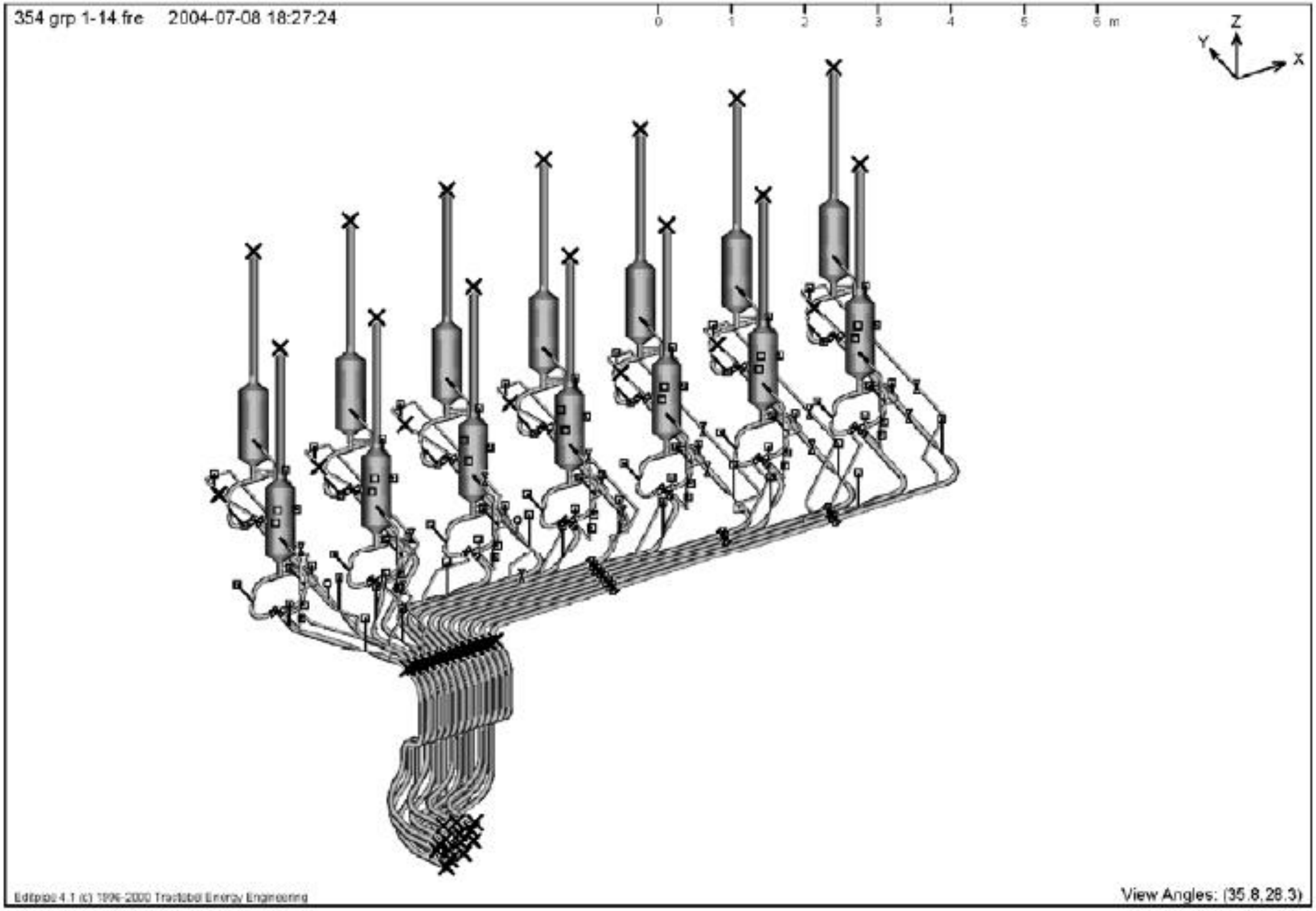
Water and steam hammers caused by

- **Pipe-breaks**
- **Valve opening (pressure relief, hydraulic scram)**
- **Rupture disc opening (pressure relief)**
- **Valve closing (isolation events)**
- **Pump trips (stops and starts)**
- **Steam collapse**

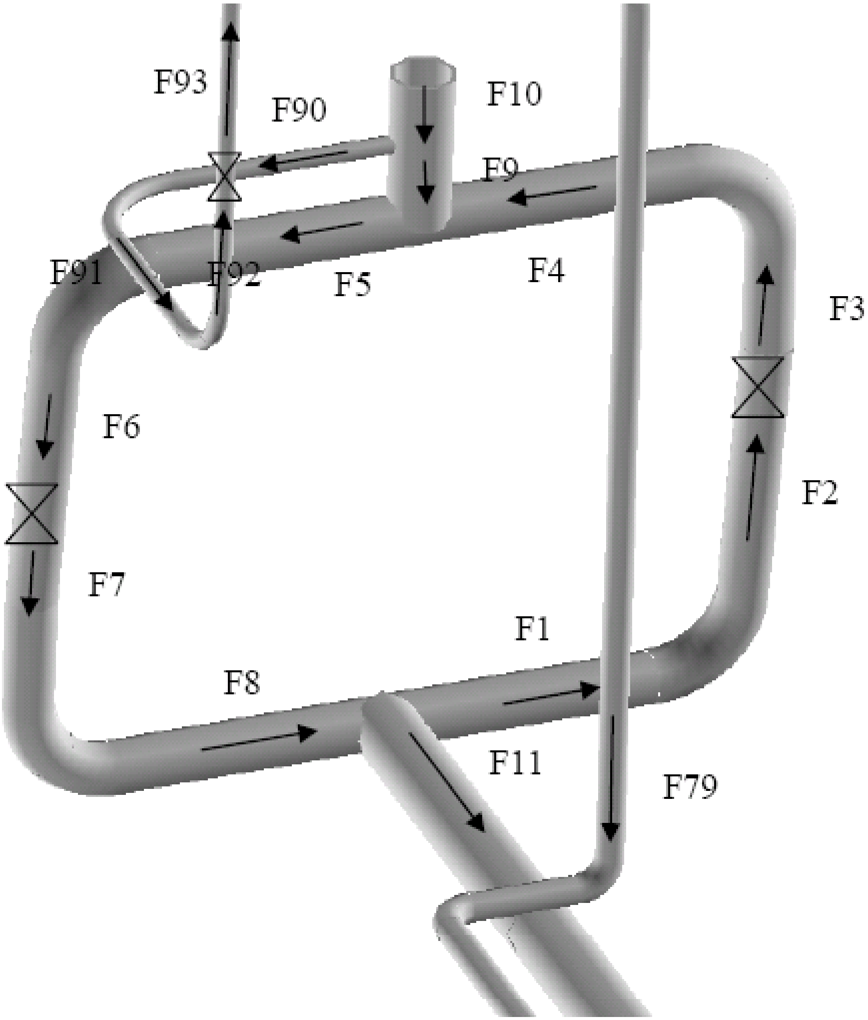
Structural analysis of piping

- **The piping system with the active components is modelled in RELAP5**
- **Boundary & initial (steady-state) conditions are imposed and the load generating event is simulated**
- **Forces are either calculated in RELAP5 during the simulation using ctrlvars or afterwards**
- **Pressures and forces as a function of time are then applied to a structural piping model and the stresses are evaluated**

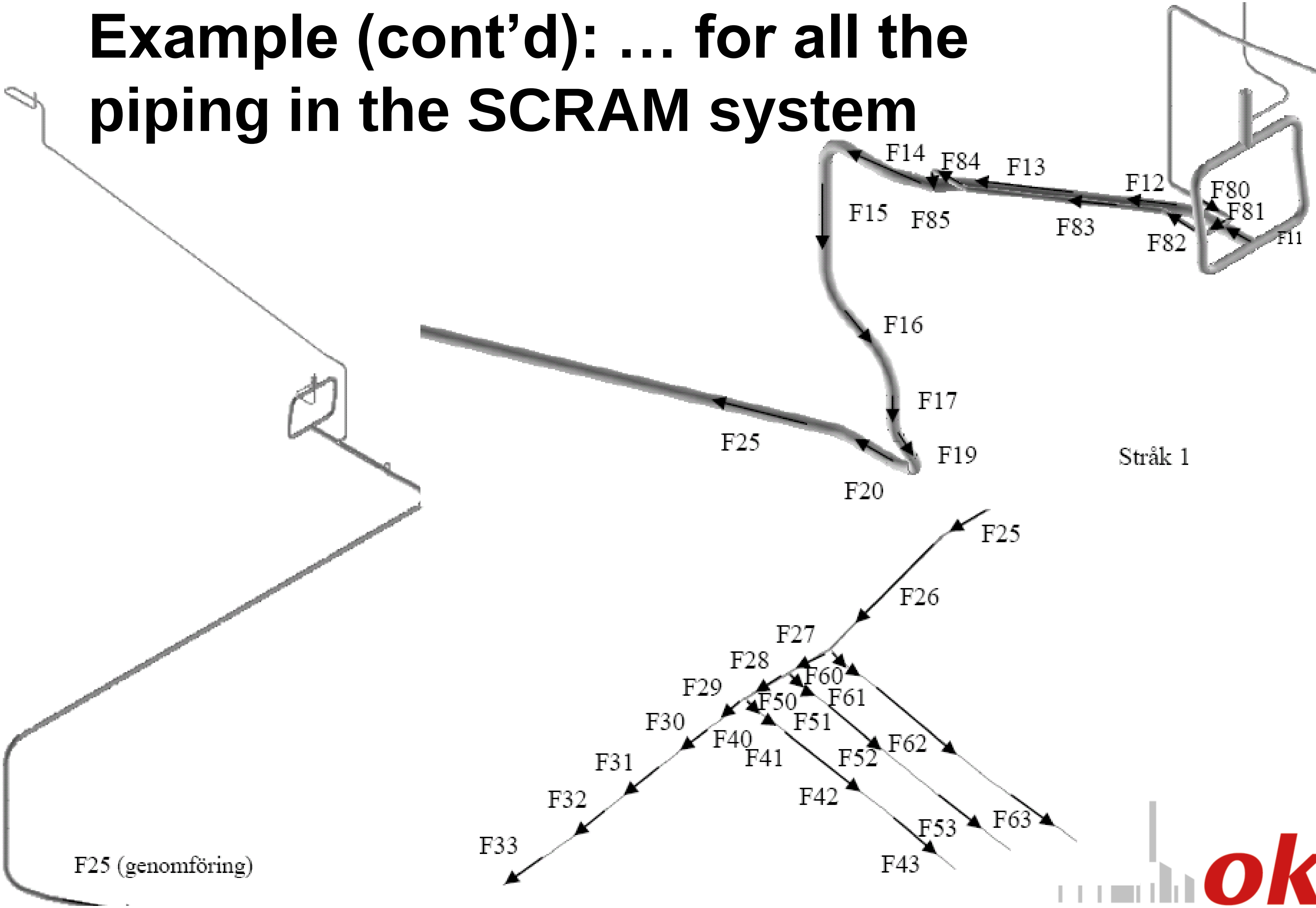
Example: The hydraulic SCRAM system of Oskarshamn Unit 1 has been modelled i RELAP5



Example (cont'd): Forces are calculated …



Example (cont'd): … for all the piping in the SCRAM system



RPV structural analysis

- The RPV with internals is modelled in RELAP5
- Boundary & initial (steady-state) conditions are imposed and the load generating event is simulated
- Pressures or mass-flows as a function of time are then applied to a structural model where the fluid is either modelled as acoustic elements, fluid elements or lumped (FSI)
- Stresses, strains and displacements are evaluated

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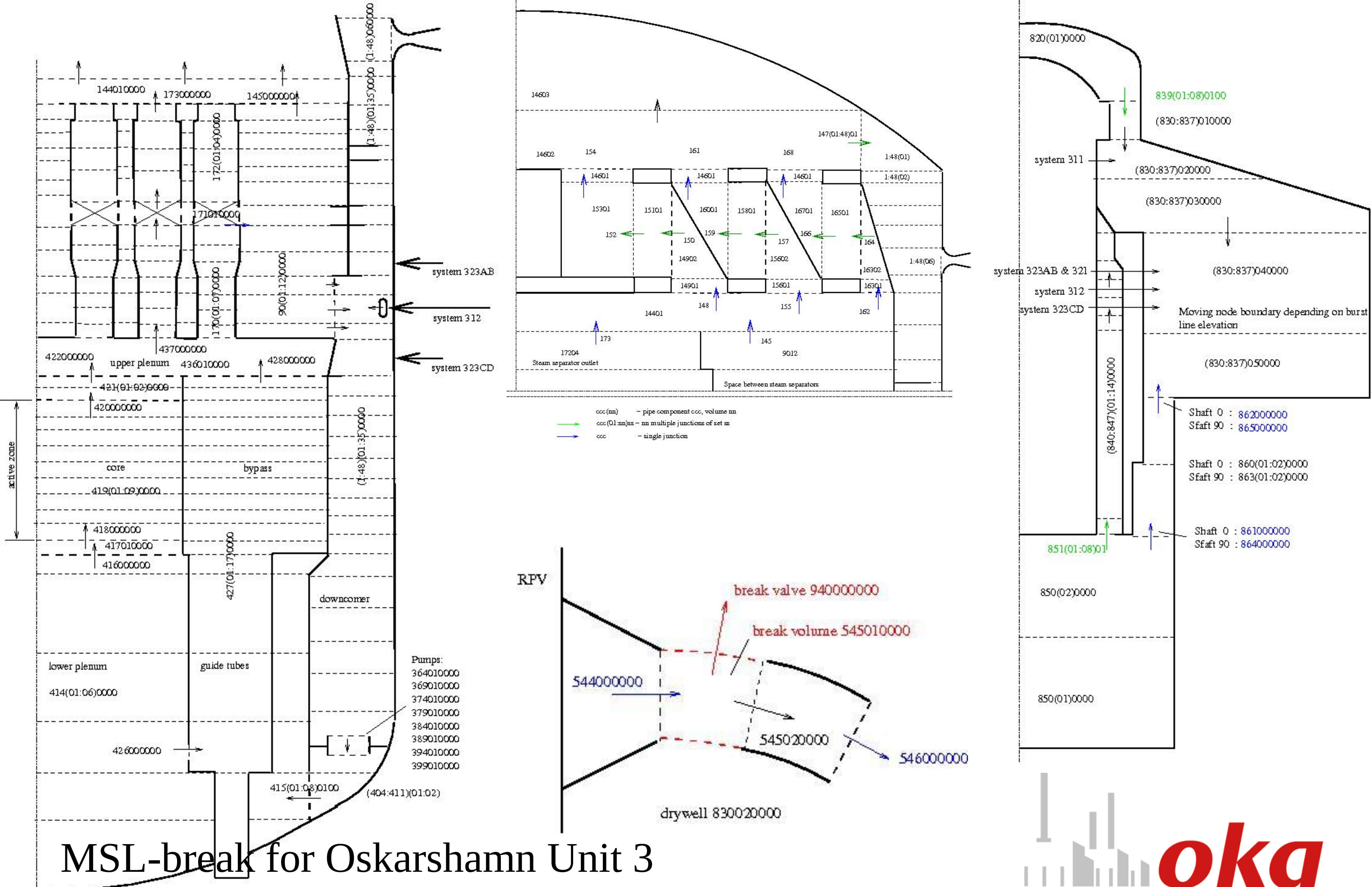

MSL-break for Oskarshamn Unit 3

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Large RELAP5 model for the RPV

- RPV with internals and containment are modelled
- Steam-lines from RPV to turbine including pressure relief system are modelled
- Feed water lines are modelled
- The SCRAM and main circulation systems are modelled along with the core
- Example of a steam-line break

test_tresca_and_deformed_svideo.avi

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Modelling considerations

- **Careful attention must be taken to ensure that the volume length is sufficiently small enough to capture the thermo-hydraulic process (pressure event) and that the time step is smaller than the Courant time step**

Large model, long execution times and large result files

- Small volume length to capture the pressure event ⇒ Large model (many components)
- Fulfilment of the Courant condition (maximum time step smaller than the Courant time step) ⇒ Long execution times
- Fast events (pipe-break, valve closure, valve opening, rupture disc opening, steam collapse, pump trip) ⇒ Rapid TH state changes ⇒ Small time step

Typical values

- **Volume lengths are typically 0,1 m for water hammer problems and 0,3 m for steam hammer problems**
- **Some consideration is taken to the piping geometry and the pressure rate change but node lengths are usually not smaller than 0,1 m**
- **The maximum time step (≈10^{-5} s) is chosen to at least fulfil the Courant limit but in some cases a smaller value is used (sensitivity analysis with respect to forces)**

Some observations

- Volume lengths are chosen smaller than the pipe diameter (violation of recommendation given on page 13, section 2.2.2.2 of volume 5 (RELAP5 Code Manual, User's Guidelines))
- RELAP5 used to determine forces in piping (not recommended on pages 4-7, section 2.1.2 of volume 5)
- Forces are not calculated directly which means either a lot of pre-processing or post-processing

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Checks

- **Sensitivity analyses with respect to the time step are always performed to check convergence of forces**
- **Parameters important to the force amplitudes are reviewed**
- **Uncertainties are analysed with respect to their effect on force amplitudes**
- **All work is reviewed by an independent third party appointed by our Swedish Regulator SSM**

Validation and verification

- Pressure, mass flows and stresses have been validated against water hammer experiments (for example HDR feed water pipe-break tests V60.4.1 and V60.5 at Karlsruhe)
- Even strains have been validated (HDR blow-down experiment test V31.1 at Karlsruhe)
- Forces have been verified against other validated codes

The future

- We will still use RELAP5 in structural analysis
- We have tested TRACE in the past but results were not very good
- We are not in a hurry to change from RELAP5 to TRACE
- Relap5-3D has been discussed

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Thank you for listening!

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```
20501200 f120 diffrend -0.10127451 0 0
20501201 cntrlvar 6120
20511200 If120-1 sum 1.0 0 1
20511201 0.0 1.0 mflowj 120010000 1.0 mflowj 120020000 1.0 mflowj 120030000
20511202 1.0 mflowj 120040000 1.0 mflowj 120050000 1.0 mflowj 120060000
20511203 1.0 mflowj 120070000 1.0 mflowj 120080000 1.0 mflowj 120090000
20511204 1.0 mflowj 120100000 1.0 mflowj 120110000 1.0 mflowj 120120000
20511205 1.0 mflowj 120130000 1.0 mflowj 120140000 1.0 mflowj 120150000
20511206 1.0 mflowj 120160000 1.0 mflowj 120170000 1.0 mflowj 120180000
20511207 1.0 mflowj 120190000 1.0 mflowj 120200000
20521200 If120-2 sum 1.0 0.0 1
20521201 0.0 1.0 mflowj 120210000 1.0 mflowj 120220000 1.0 mflowj 120230000
20521202 1.0 mflowj 120240000 1.0 mflowj 120250000 1.0 mflowj 120260000
20521203 1.0 mflowj 120270000 1.0 mflowj 120280000 1.0 mflowj 120290000
20521204 1.0 [illegible] 120320000
20521205 1.0 mflowj 120330000 1.0 mflowj 120340000 1.0 mflowj 120350000
20521206 1.0 mflowj 120360000 1.0 mflowj 120370000 1.0 mflowj 120380000
20521207 1.0 mflowj 120390000 1.0 mflowj 120400000
20531200 If120-3 sum 1.0 0.0 1
20531201 0.0 1.0 mflowj 120410000 1.0 mflowj 120420000 1.0 mflowj 120430000
20531202 1.0 [illegible] 120460000
20531203 1.0 [illegible] 120490000
20531204 1.0 mflowj 120500000
20561200 If120 sum 1.0 0.0 1
20561201 0.0 0.5 mflowj 121000000 0.5 mflowj 116000000
20561202 1.0 cntrlvar 1120 1.0 cntrlvar 2120
20561203 1.0 cntrlvar 3120
20561204 1.0 cntrlvar 6115
```

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Calculation of forces

$$F_R = F_I + F_W + F_G =$$

$$-\sum \int \left(\rho u \left(n \cdot u \right) + n \left(p - p_a \right) \right) \mathrm{d}S +$$

$$-\int_{\mathrm{V}} \frac{\partial \left(\rho u \right)}{\partial t} \mathrm{d}V +$$

$$+\int_{\mathrm{V}} \rho \, \mathrm{g} \, \mathrm{d}V$$

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Calculation of forces (cont'd)

- F_I Blow-down force (pipe with open end)
- F_W Wave force (dominating term for a straight pipe run between two bends)
- F_G Gravity force (often negligible)

$$F_W = -\frac{L}{N}\frac{\mathrm{d}}{\mathrm{d}t}\sum_i \dot{m}_i$$

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Example: One pipe component with force calculation (next slide)

```
**********************************************************
* pipe component 120 length 5.165 m inner diameter 0.0273 m
**********************************************************
1200000 unnamed pipe
* pipe component number of volumes
1200001 51
* pipe x-coord volume flow areas
1200101 0.000585 51
* pipe x-coord junction flow areas
1200201 0.000585 50
* pipe x-coord volume lengths
1200301 0.101275 51
* pipe component volumes azimuthal angles
1200501 0.0 51
* pipe component volumes vertical angles
1200601 90.0 51
* rough hd vol num
1200801 0.000002 0.0273 51
* fwd. loss rev. loss junc num
1200901 0.0 0.0 50
* vol flags vol num
1201001 0 51
* jun flags junc num
1201101 0 50
* ebt press temp
1201201 3 7.20e+06 513.0 0 0 0 51
* ctrl word
1201300 1
* flowf flowg velj junc num
1201301 0.0 0.0 0.0 50
```

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```
***********************************************************
* pipe reaction force
***********************************************************
20501200 f120 diffrend -0.10127451 0 0
20501201 cntrlvar 6120
20511200 If120-1 sum 1.0 0 1
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120030000
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120060000
20511203 1.0 mflowj 120070000 1.0 mflowj 120080000 1.0 mflowj
120090000
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120120000
20511205 1.0 mflowj 120130000 1.0 mflowj 120140000 1.0 mflowj
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120180000
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20521200 If120-2 sum 1.0 0.0 1
20521201 0.0 1.0 mflowj 120210000 1.0 mflowj 120220000 1.0 mflowj
120230000
20521202 1.0 mflowj 120240000 1.0 mflowj 120250000 1.0 mflowj
120260000
20521203 1.0 mflowj 120270000 1.0 mflowj 120280000 1.0 mflowj
120290000
20521204 1.0 mflowj 120300000 1.0 mflowj 120310000 1.0 mflowj
120320000
20521205 1.0 mflowj 120330000 1.0 mflowj 120340000 1.0 mflowj
120350000
20521206 1.0 mflowj 120360000 1.0 mflowj 120370000 1.0 mflowj
120380000
20521207 1.0 mflowj 120390000 1.0 mflowj 120400000
20531200 If120-3 sum 1.0 0.0 1
20531201 0.0 1.0 mflowj 120410000 1.0 mflowj 120420000 1.0 mflowj
120430000
20531202 1.0 mflowj 120440000 1.0 mflowj 120450000 1.0 mflowj
120460000
20531203 1.0 mflowj 120470000 1.0 mflowj 120480000 1.0 mflowj
120490000
20531204 1.0 mflowj 120500000
20561200 If120 sum 1.0 0.0 1
20561201 0.0 0.5 mflowj 121000000 0.5 mflowj 116000000
20561202 1.0 cntrlvar 1120 1.0 cntrlvar 2120
20561203 1.0 cntrlvar 3120
20561204 1.0 cntrlvar 6115
```

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Alternative calculation of forces

Numerical derivation can cause numerical problems (non-physical 'spikes'). The following expression is then sometimes used

$$F = p_2 + \rho_2 u_2^2 + \sum_{i=0}^{n} \frac{\lambda}{4r} \rho_i |u_i| u_i \Delta x - p_1 - \rho_1 u_1^2$$

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